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Presented for filing is a new original patent application of:

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ROTH, KAYLA CHALMERS, JUAN REVILLA AND RAVI P. SINGH

Title: VARIABLE WIDTH INSTRUCTION ALIGNMENT ENGINE

Enclosed are the following papers, including those required to receive a filing date  
under 37 CFR §1.53(b):

	Pages
Specification	15
Claims	6
Abstract	1
Declaration	[To be Filed at a Later Date]
Drawing(s)	5

Enclosures:  
— Postcard.

There are 24 total claims, 4 of which are independent.

Basic filing fee	\$0
Total claims in excess of 20 times \$18	08
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Total filing fee:	\$0

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APPLICATION  
FOR  
UNITED STATES LETTERS PATENT

TITLE: VARIABLE WIDTH INSTRUCTION ALIGNMENT  
ENGINE

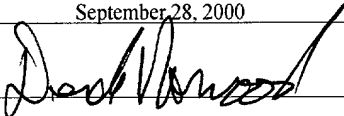
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003650 284001 P9291

# **VARIABLE WIDTH INSTRUCTION ALIGNMENT ENGINE**

## **TECHNICAL FIELD**

This invention relates to digital signal processors, and more particularly to alignment of instructions of variable widths within a digital signal processor.

## **BACKGROUND**

Digital signal processing is concerned with the representation of signals in digital form and the transformation or processing of such signal representation using numerical computation. Digital signal processing is a core technology for many of today's high technology products in fields such as wireless communications, networking, and multimedia. One reason for the prevalence of digital signal processing technology has been the development of low cost, powerful digital signal processors (DSPs) that provide engineers the reliable computing capability to implement these products cheaply and efficiently. Since the development of the first DSPs, DSP architecture and design have evolved to the point where even sophisticated real-time processing of video-rate sequences may be performed.

DSPs are often used for a variety of multimedia applications such as digital video, imaging, and audio. DSPs

may manipulate the digital signals to create and open such multimedia files.

MPEG-1 (Motion Picture Expert Group), MPEG-2, MPEG-4 and H.263 are digital video compression standards and file formats. These standards achieve a high compression rate of the digital video signals by storing mostly changes from one video frame to another, instead of storing each entire frame. The video information may then be further compressed using a number of different techniques.

The DSP may be used to perform various operations on the video information during compression. These operations may include motion search and spatial interpolation algorithms. The primary intention is to measure distortion between blocks within adjacent frames. These operations are computationally intensive and may require high data throughput.

The MPEG family of standards is evolving to keep pace with the increasing bandwidth requirements of multimedia applications and files. Each new version of the standard presents more sophisticated algorithms that place even greater processing requirements on the DSPs used in MPEG compliant video processing equipment.

Video processing equipment manufacturers often rely on application-specific integrated circuits (ASICs) customized

for video encoding under the MPEG and H.263 standards.  
However, ASICs are complex to design, costly to produce and less flexible in their application than general-purpose DSPs.

# **DESCRIPTION OF DRAWINGS**

5           These and other features and advantages of the invention will become more apparent upon reading the following detailed description and upon reference to the accompanying drawings.

10           Figure 1 is a block diagram of a mobile video device utilizing a processor according to one embodiment of the present invention.

          Figure 2 is a block diagram of a signal processing system according to an embodiment of the present invention.

15           Figure 3 is a block diagram of an alternative signal processing system according to an embodiment of the present invention.

          Figure 4 illustrates exemplary pipeline stages of the processor in Figure 1 according to an embodiment of the present invention.

20           Figure 5 is a logic diagram of the data flow in an alignment mux according to one embodiment of the present invention.

Figure 6 is a block diagram of an instruction request unit according to one embodiment of the present invention.

Figure 7 illustrates the process of aligning the variable width instructions according to one embodiment of the present invention.

#### DETAILED DESCRIPTION

Figure 1 illustrates a mobile video device 100 including a processor according to an embodiment of the invention. The mobile video device 100 may be a hand-held device which displays video images produced from an encoded video signal received from an antenna 105 or a digital video storage medium 120, e.g., a digital video disc (DVD) or a memory card. A processor 110 communicates with a memory 115 (which may be a cache memory) which may store instructions and data for the processor operations. The processor 110 may be a microprocessor, a digital signal processor (DSP), a microprocessor controlling a slave DSP, or a processor with an hybrid microprocessor/DSP architecture. For the purposes of this application, the processor 110 will be referred to hereinafter as a DSP 110.

The DSP 110 may perform various operations on the encoded video signal, including, for example, analog-to-digital conversion, demodulation, filtering, data recovery,

and decoding. The DSP 110 may decode the compressed digital video signal according to one of various digital video compression standards such as the MPEG-family of standards and the H.263 standard. The decoded video signal may then be  
5 input to a display driver 130 to produce the video image on a display 125.

Hand-held devices generally have limited power supplies. Also, video decoding operations are computationally intensive. Accordingly, a processor for use in such a device  
10 is advantageously a relatively high speed, low power device.

The DSP 110 may have a deeply pipelined, load/store architecture. By employing pipelining, the performance of the DSP may be enhanced relative to a non-pipelined DSP. Instead of fetching a first instruction, executing the first  
15 instruction, and then fetching a second instruction, a pipelined DSP 110 fetches the second instruction concurrently with execution of the first instruction, thereby improving instruction throughput. Further, the clock cycle of a pipelined DSP may be shorter than that of a non-pipelined DSP,  
20 in which the instruction must be fetched and executed in the same clock cycle.

Such a DSP 110 may be used with video camcorders, teleconferencing, PC video cards, and High-Definition Television (HDTV). In addition, the DSP 110 may also be used



in connection with other technologies utilizing digital signal processing such as voice processing used in mobile telephony, speech recognition, and other applications.

Turning now to Figure 2, a block diagram of a signal processing system 200 including DSP 110 according to an embodiment is shown. One or more analog signals may be provided by an external source, e.g., antenna 105, to a signal conditioner 202. Signal conditioner 202 is may perform certain preprocessing functions upon the analog signals. Exemplary preprocessing functions may include mixing several of the analog signals together, filtering, amplifying, etc. An analog-to-digital converter (ADC) 204 may be coupled to receive the preprocessed analog signals from signal conditioner 202 and to convert the preprocessed analog signals to digital signals consisting of samples, as described above. The samples may be taken according to a sampling rate determined by the nature of the analog signals received by signal conditioner 202. The DSP 110 may be coupled to receive digital signals at the output of the ADC 204. The DSP 110 may perform the desired signal transformation upon the received digital signals, producing one or more output digital signals. A digital-to-analog converter (DAC) 206 may be coupled to receive the output digital signals from the DSP 110. The DAC 206 converts the output digital signals into output analog

signals. The output analog signals are then conveyed to another signal conditioner 208. The signal conditioner 208 performs post-processing functions upon the output analog signals. Exemplary post-processing functions are similar to the preprocessing functions listed above. It is noted that various alternatives of the signal conditioners 202 and 208, the ADC 204, and the DAC 206 are well known. Any suitable arrangement of these devices may be coupled into a signal processing system 200 with the DSP 110.

Turning next to Figure 3, a signal processing system 300 according to another embodiment is shown. In this embodiment, a digital receiver 302 may be arranged to receive one or more digital signals and to convey the received digital signals to the DSP 110. As with the embodiment shown in Figure 2, DSP 110 may perform the desired signal transformation upon the received digital signals to produce one or more output digital signals. Coupled to receive the output digital signals may be a digital signal transmitter 304. In one exemplary application, the signal processing system 300 is a digital audio device in which the digital receiver 302 conveys to the DSP 110 digital signals indicative of data stored on the digital storage device 120. The DSP 110 then processes the digital signals and conveys the resulting output digital signals to the digital transmitter 304. The digital

transmitter 304 then causes values of the output digital signals to be transmitted to the display driver 130 to produce a video image on the display 125.

The pipeline illustrated in Figure 4 includes eight stages, which may include instruction fetch 402-403, decode 404, address calculation 405, execution 406-408, and write-back 409 stages. An instruction *i* may be fetched in one clock cycle and then operated on and executed in the pipeline in subsequent clock cycles concurrently with the fetching of new instructions, e.g., *i*+1 and *i*+2.

Pipelining may introduce additional coordination problems and hazards to processor performance. Jumps in the program flow may create empty slots, or "bubbles," in the pipeline. Situations which cause a conditional branch to be taken or an exception or interrupt to be generated may alter the sequential flow of instructions. After such an occurrence, a new instruction may be fetched outside of the sequential program flow, making the remaining instructions in the pipeline irrelevant. Methods such as data forwarding, branch prediction, and associating valid bits with instruction addresses in the pipeline may be employed to deal with these complexities.

Figure 5 is a logic diagram of the data flow 500 in an alignment mux according to one embodiment of the present

invention. In the data flow 500, instructions are loaded into the memory 505. The memory 505 includes a plurality of buffers 510, 515 for storing the instructions. In one embodiment, the buffers 510, 515 are 64-bit buffers. The first buffer 510 is divided into a plurality of smaller, 16-bit buffers 520, 525, 530, and 535. The second buffer 515 is also divided into a plurality of smaller, 16-bit buffers 540, 545, 550, and 555. Each of the smaller, 16-bit buffers 520-555 is connected to a plurality of selection multiplexers 560, 565, 570, and 575. Each of the selection multiplexers 560, 565, 570, 575 are connected to a select line 580 to select the output of the multiplexers 560, 565, 570, and 575. The multiplexers 560, 565, 570, and 575 each outputs a 16-bit signal which is stored in a plurality of flops 585, 587, 590, and 592 for use in the pipeline.

The signals stored in the plurality of flops 585, 587, 590, and 592 may represent the instruction to be executed in the pipeline. If the instruction is 16-bits or less, only the first flop 585 may contain data. As the instruction size increases, more of the flops 585-592 will contain data. For example, a 32-bit instruction may have data in the first flop 585 and the second flop 587 while a 64-bit instruction may have data in all the flops 585-592.

An individual instruction may be initially split among the plurality of 16-bit buffers 520-555. For example, a 64-bit instruction may begin in the third buffer 530 and end in the sixth buffer 545. The alignment mux of Figure 5 ensures that this instruction is aligned prior to processing in the pipeline by transferring the data to the plurality of multiplexers 560-575 and then selecting the proper data to send to the flops 585-592. To reduce the risk that bubbles are not inserted in the pipeline, the alignment mux reloads buffers 510, 515 in the memory 505 once all the instruction data in the buffers 510, 515 is dispatched to the pipeline. In one embodiment, the memory 505 may be a cache memory.

The present invention is described using a 64-bit instruction register providing instructions of 64-bits or smaller. Of course, the invention may be accomplished on any size instruction register (N-bit) providing instructions of (N-bits) or smaller. Further, although the present invention is described with two buffers 510, 515, the invention may be scaled to any size to accommodate any number of buffers.

Figure 6 is a block diagram of an instruction request unit 600 according to one embodiment of the present invention. The instruction request unit 600 may look ahead several cycles to determine when the buffers 510, 515 will be emptied so the buffers 510, 515 may be reloaded without any bubbles being

introduced into the pipeline in this particular embodiment.

The embodiment of the instruction request unit 600 will be described with a cache latency of 2 cycles. Thus, the instruction request unit should look ahead 2 cycles to ensure the buffers 510, 515 are continually reloaded. It can be appreciated that the present invention may be used in a system have a variety of cache latencies, and the instruction request unit 600 would need to look ahead a number of cycles at least equal to the cache latency to ensure no bubbles are inserted.

Of course, the instruction request unit 600 may look ahead less than the cache latency. In this embodiment, bubbles may be inserted into the pipeline.

The instruction request unit 600 receives instruction data from the buffers 510, 515 which are input into an alignment multiplexer 615. The alignment multiplexer 615 may align the current instruction data received from the buffers 510, 515 and outputs individual instructions parsed from the instruction data. The data flow in the alignment multiplexer 615 is described above with reference to Figure 5. When an individual instruction is received from the alignment multiplexer 615, the instruction is pre-decoded to generate width bits. The width of the instruction (cur\_width) is decoded in block 620 from width bits associated with the instruction. In one embodiment, the width bits are a 2-bit

signal indicating the width of the current instruction. With a 2-bit signal, there are 4 possible width values. For example, width bits of 00 indicates the instruction is invalid, width bits of 01 indicates a 16-bit instruction, width bits of 10 indicates a 32-bit instruction, and width bits of 11 indicates a 64-bit instruction.

A multiplexer 628 receives a branch target address and the current state (cstate) of the instruction position in the buffers 510, 515. The multiplexer 628 selects either the branch target address or the current state to load the flop 630 with either the current state of the branch target address, which may become the current state. The current state is then combined with the width of the current instruction in block 625. By combining the current state with the current width, the position of the beginning of the next instruction (nstate) may be determined. This position information is then supplied to a second alignment multiplexer 635 to be used in aligning the next instruction. The next instruction position information may also feed back to the flop 630 at the next clock cycle. At the next clock cycle, the next instruction position becomes the current instruction position, and this information is updated in the flop 630. The next instruction position is also supplied to the transition block 645 to aid in determining is a transition

from the first buffer 510 to the second buffer 515 has occurred.

The second alignment multiplexer 635 receives as inputs instruction data from the buffers 510' and 515'. The buffers 510' and 515' may be the same as the buffers 510 and 515, or may contain new data. The buffers 510' and 515' may contain new data for the next instruction if the buffers 510 and 515 have been exhausted. The second alignment buffer 635 aligns the next instruction in the same manner the first alignment buffer 615 aligns the first instruction. The width of the next instruction is then pre-decoded in block 640 to determine the corresponding width bits. The width information (next\_width) is then supplied to a transition logic in block 645.

The transition logic determines whether either of the buffers 510 and 515 will be emptied after processing of the next instruction. The transition block 645 includes the next state position and the next instruction width as inputs. The transition block 645 then determines based on the next state position and instruction width whether either of the buffers 510 and 515 will be exhausted after the next instruction. For example, if the next state position indicated is the beginning of the 16-bit buffer 530 and the next instruction width is 64-bits, the transition block 645



determines that the instruction will be taken from the 16-bit buffers 530, 535, 540, and 545, thus completely emptying the first buffer 510. The transition block 645 may then send a signal to the flop 650 indicating that the first buffer 510 is available to be reloaded, which may generate a requires to the memory to fill the empty buffer 510.

The transition block 645 may also determine a buffer 510, 515 is depleted by comparing the most significant bits (MSB) of pointers to the buffers 520-555. For example, each of the 16-bit buffers 520-555 may have an associated pointer. Because there are eight 16-bit buffers, three-bit pointers are used to uniquely identify each buffer. In one embodiment, the buffer 520 has a pointer value of 000, the buffer 525 has a pointer value of 001, the buffer 530 has a pointer value of 010, the buffer 535 has a pointer value of 011, the buffer 540 has a pointer value of 100, the buffer 545 has a pointer value of 101, the buffer 550 has a pointer value of 110, and the buffer 555 has a pointer value of 111. Thus, each of the 16-bits buffers 520, 525, 530, and 535 that comprise the larger buffer 510 have pointer values in which the most significant bit is "0". Each of the 16-bit buffers 540, 545, 550, and 555 that comprise the larger buffer 515 have pointer values in which the most significant bit is "1".

As stated above, an instruction may occupy a plurality of the 16-bit buffers 520-555. For example, a 64-bit instruction may begin in buffer 525 and end in buffer 540. The pointer value of the buffer 525 at the beginning of the instruction is 001, and the pointer value of the buffer 540 at the end of the instruction is 100. Thus, the most significant bit of the buffer pointer changes from "0" to "1", thereby indicating a transition from the buffer 510 to the buffer 515. By comparing the most significant bits of the pointers to the buffers 520-555, the transition between the buffers 510 and 515 may be determined.

In another embodiment of the invention, counters are used to manage the number of requests made to load the buffers. Each time a load request is made, the counter may be incremented. The counter may decrement when the buffer is emptied. When the value of the counter equals the number of buffers, the present invention stops making requests. Therefore, the counters may be checked prior to issuing a load request to determine if a buffer is available to accept data.

Numerous variations and modifications of the invention will become readily apparent to those skilled in the art. Accordingly, the invention may be embodied in other specific forms without departing from its spirit or essential characteristics.

**WHAT IS CLAIMED IS:**

1                   1.    A method of aligning instructions in a  
2   processor comprising:

3                   aligning a first instruction;

4                   decoding the size of the first instruction;

5                   determining the beginning of a second instruction  
6   based on the size of the first instruction;

7                   decoding the size of the second instruction;

8                   determining whether processing the second  
9   instruction will deplete one of a plurality of buffers; and

10                  instructing the one of the plurality of buffers to  
11   receive additional data if processing the second instruction  
12   depletes the one of the plurality of buffers.

1                   2.    The method of Claim 1, further comprising  
2   storing the plurality of instructions in a plurality of sub-  
3   buffers.

1                   3.    The method of Claim 1, further comprising  
2   comparing a most significant bit of a pointer to a first of  
3   the plurality of sub-buffers to a most significant bit of a  
4   pointer to a second of the plurality of sub-buffers to

5 determine whether processing one of the plurality of  
6 instructions will deplete a buffer.

1 4. The method of Claim 1, further comprising  
2 storing a first instruction across a plurality of storage  
3 elements prior to processing the instructions.

1 5. The method of Claim 1, further comprising  
2 adding the size of the first instruction to a current  
3 instruction position to determine the beginning of the second  
4 instruction.

5 6. The method of Claim 1, further comprising  
6 aligning ahead a number of cycles equal to a cache latency.

1 7. The method of Claim 1, further comprising  
2 aligning instructions in a digital signal processor.

3 8. The method of Claim 1, further comprising  
4 issuing a request to a memory to reload the plurality of  
5 buffers.

1 9. A method of processing instructions within a  
2 processor comprising:

3 predicting whether one of a plurality of buffers  
4 will be depleted of instruction data within a number of cycles  
5 approximately equal to a cache latency;

6 preparing the one of a plurality of buffers to be  
7 loaded with additional instruction data if the one of the  
8 plurality of buffers will be depleted.

1 10. The method of Claim 9, further comprising  
2 decoding the size of the a first instruction in the  
3 instruction data;

4 determining the beginning of a second instruction in  
5 the instruction data based on the size and position of the  
6 first instruction; and

7 decoding the size of the second instruction.

8 11. The method of Claim 9, wherein the plurality of  
9 buffers are divided into a plurality of sub-buffers.

10 12. The method of Claim 11, wherein the predicting  
11 is accomplished by comparing a most significant bit of a  
12 pointer to a first of the plurality of sub-buffers to a most  
13 significant bit of a pointer to a second of the plurality of  
14 sub-buffers to determine whether processing one of the  
15 plurality of instructions will deplete one of a plurality of  
16 buffers.

1 13. The method of Claim 9, further comprising  
2 aligning the instruction data.

1           14. The method of Claim 9, further comprising  
2           processing the instructions in a digital signal processor.

1           15. The method of Claim 9, further comprising  
2           issuing a request to reload the plurality of buffers.

1           16. A processor comprising:  
  
2           a plurality of buffers adapted to store first  
3           instruction data including a plurality of instructions;  
  
4           an instruction request unit adapted to align the  
5           plurality of instructions for execution;  
  
6           a width decoder adapted to determine the size of the  
7           plurality of instructions;  
  
8           a transition detector adapted to predict when one of  
9           the plurality of buffers will be empty, the transition  
10          detector adapted to send a signal to instruct one of the  
11          plurality of buffers to load a second instruction data.

1           17. The processor of Claim 16, wherein the  
2           plurality of buffers is divided into a plurality of sub-  
3           buffers.

1           18. The processor of Claim 16, wherein the  
2           transition detector compares a most significant bit of a  
3           pointer to a first of the plurality of sub-buffers to a most

4 significant bit of a pointer of a second of the plurality of  
5 sub-buffers to determine whether processing one of the  
6 plurality of instructions will deplete a buffer.

1 19. The processor of Claim 16, wherein the  
2 processor aligns ahead a number of cycles equal to a cache  
3 latency.

1 20. The processor of Claim 16, wherein the  
2 processor is a digital signal processor.

3 21. An apparatus, including instructions residing  
4 on a machine-readable storage medium, for use in a machine  
5 system to align instructions in a processor, the instructions  
6 causing the machine to:

7 receive data containing instructions in a plurality  
8 of buffers;

9 decode the size of a first instruction;

10 determine the beginning of a second instruction  
11 based on the size of the first instruction;

12 decode the size of the second instruction;

determine whether processing the second instruction  
will deplete one of the plurality of buffers; and

13           instruct the one of the plurality of buffers to  
14           receive additional data if processing the second instruction  
15           depletes the one of the plurality of buffers.

1           22. The apparatus of Claim 21, wherein the  
2           plurality of instructions are stored in a plurality of sub-  
3           buffers.

1           23. The apparatus of Claim 21, wherein a most  
2           significant bit of a pointer to a first of the plurality of  
3           sub-buffers is compared to a most significant bit of pointer  
4           to a second of the plurality of sub-buffers to determine  
5           whether processing one of the plurality of instructions will  
6           deplete a buffer.

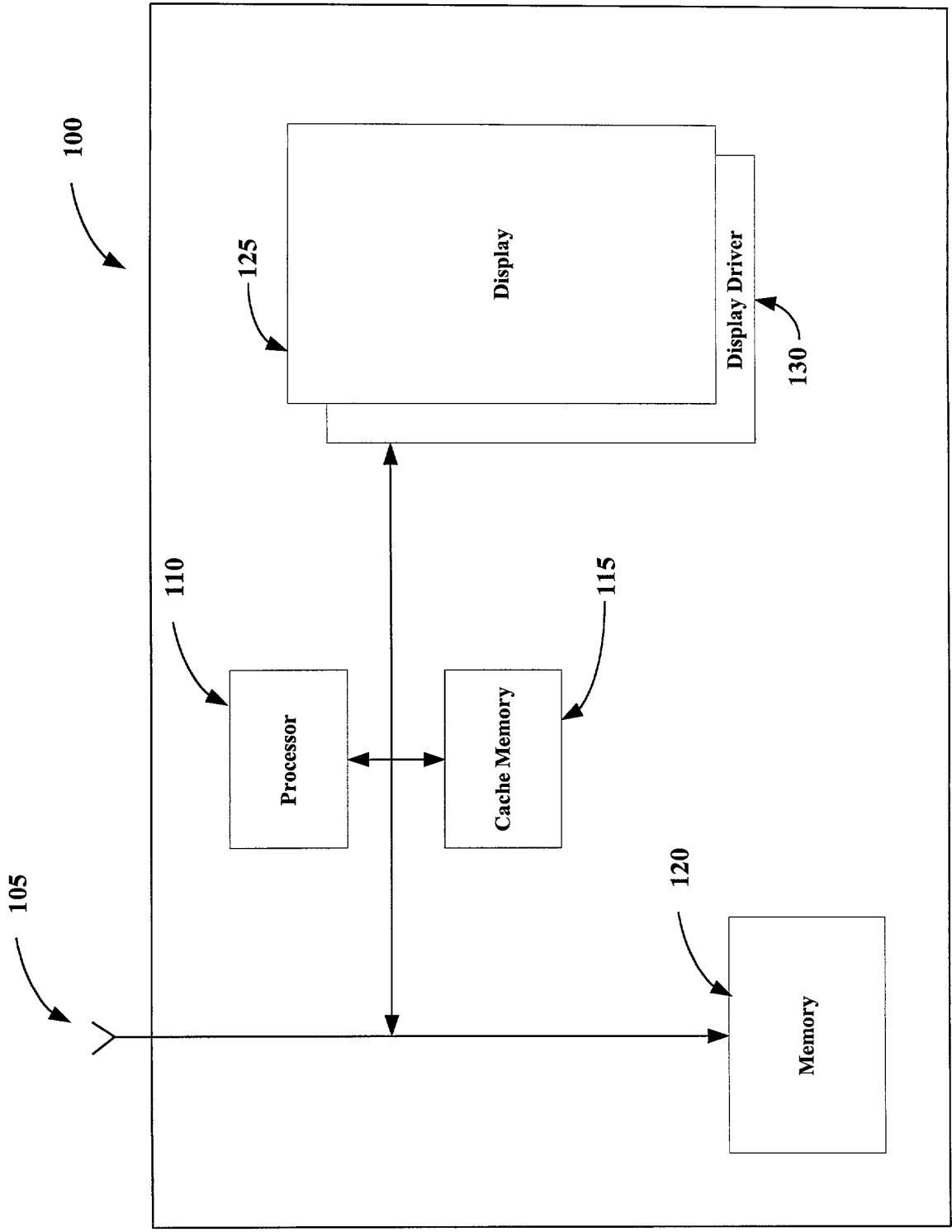
1           24. The apparatus of Claim 21, wherein a first  
2           instruction is stored across a plurality of storage elements  
3           prior to processing the instructions.



**ABSTRACT**

In one embodiment, a digital signal processor includes look ahead logic to decrease the number of bubbles inserted in the processing pipeline. The processor receives data containing instructions in a plurality of buffers and  
5 decodes the size of a first instruction. The beginning of a second instruction is determined based on the size of the first instruction. The size of the second instruction is decoded and the processor determines whether loading the  
10 second instruction will deplete one of the plurality of buffers.

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**Figure 1**





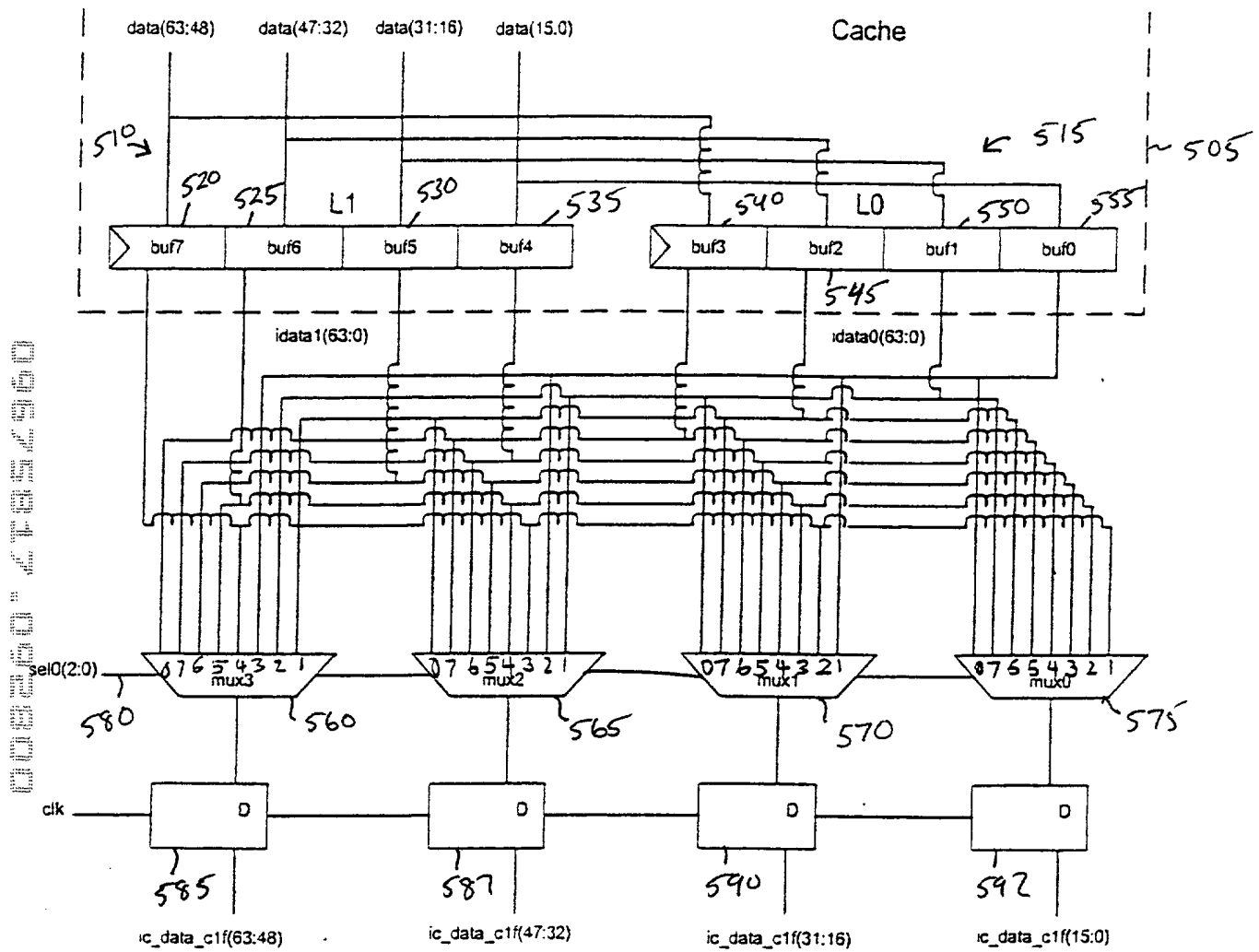
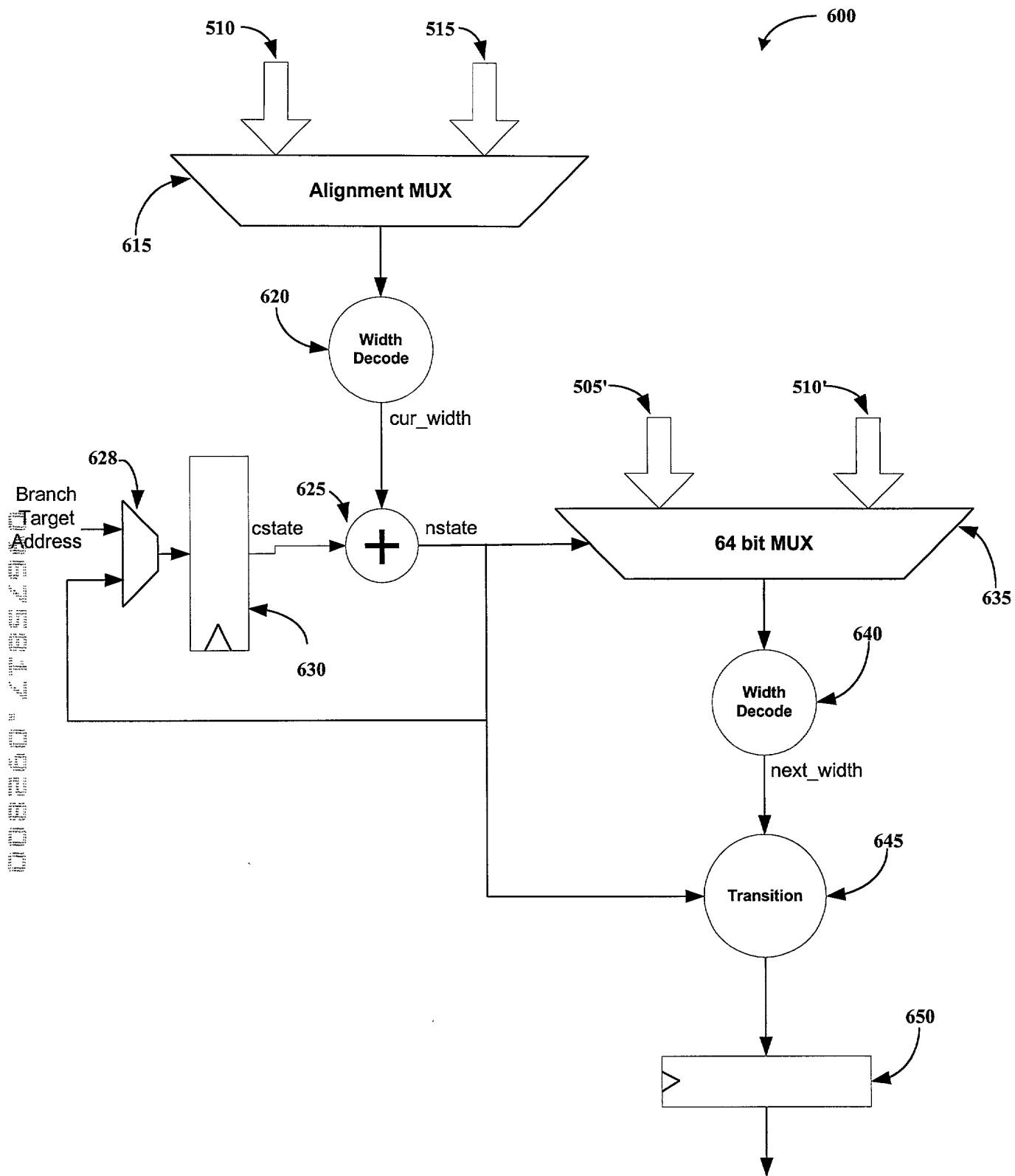


Figure 5



**Figure 6**